Quantitative phase microscopy for simultaneous thermal conductivity and thermo-optic coefficient measurement

NIMS[1], Univ. of Tsukuba[2], Univ. of Tokyo[3], JST-PRESTO[4]
○(D1) Nicholaus K. Tanjaya[1,2], Keiichiro Toda,[3] Takuro Ideguchi,[3] Satoshi Ishii[1,2,4]
E-mail: sishii@nims.go.jp

1. Introduction

An optical image captured by a quantitative phase microscope (QPM) has image contrast proportional to phase shift, which differentiates from phase contrast microscope and differential interference contrast microscope. The measured phase reflects not only the intrinsic but also the extrinsic refractive index of a sample. Therefore, QPM has been applied to measure the physical properties of the materials, such as transmittance[1], surface temperature[2], and electrical impedance[3]. In the current research, we demonstrate a method based on QPM to measure a transparent substrate's thermal conductivity and thermo-optic coefficient (TOC) simultaneously.

2. Method

A quantitative phase microscope was built using a commercial inverted microscope, with an additional external laser (785 nm, CW) for photothermal heating and a 4f-system optic for spatial filtering as shown in Fig. 1. 50-nm thick titanium nitride (TiN) thin films were sputtered on five different substrates (glass, fused silica, sapphire, titanium dioxide, and strontium titanate) where TiN acted as optical absorbers to generate heat at the surfaces. The phase difference was calculated using Fourier transform and inverse Fourier transform by subtracting the reconstructed phase of the heated state and non-heated state. Then, a semi-analytical model was built to model laser power dependent phase shifts of substrates. The thermal conductivity and TOC of a substrate were obtained by fitting the measured phase shift.

Fig. 1. Schematic of measurement setup.

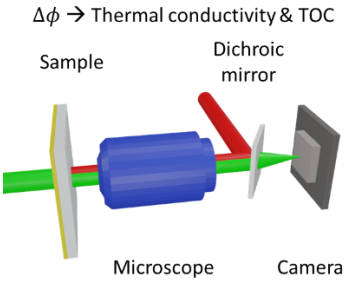

Table 1. Extracted thermal conductivities and TOCs of substrates. Reference values are also shown.

Substrate	Measured thermal conductivity (W/m/K)	Reference thermal conductivity (W/m/K)	Measured thermo-optic coefficient (×1E-5 K^{-1})	Reference thermo-optic coefficient (×1E-5 K^{-1})
Glass	0.87 ± 0.55	1.1[4]	1.3 ± 0.74	0.22[9]
Fused silica	0.93 ± 0.21	1.4[5]	1.1 ± 0.20	1.1[9]
Sapphire	33 ± 5.1	32[6]	1.5 ± 0.17	1.2[10]
Titanium dioxide	6.0 ± 2.7	7.1[7]	-6.5 ± 2.9	−6.9[11]
Strontium titanate	16 ± 1.3	12[8]	-6.4 ± 0.44	−4.9[11]

3. Results and discussion

The extracted thermal conductivities and TOCs are tabulated in Table 1. The results show that the measured thermal conductivities and TOCs agree well with the reference values, as summarized in Table 1. [4-11] As our method based on QPM is applicable for both positive and negative TOCs, our method can be used to determine the thermal conductivity and TOC of an unknown transparent substrate. Our method has the advantage of being cost-effective and able to simultaneously measure thermal conductivities and TOCs.

References

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